Cover Letter

Locating Materials with Nuclear Quadrupole Moments within Surface Coil Array Area

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14. ABSTRACT
This paper focuses on detecting solid state materials that have a nuclear quadrupole moment using surface coil arrays. With surface coils in the array decoupled from one another, the location and dimension of the material can determined based on the nuclear quadrupole resonance (NQR) signal strength from the surface coil in the array. Experimental investigations will be used with two 7â diameter, single turn, surface coils overlapping for decoupling, and tuned to detect the unique 28.1MHz NQR frequency from potassium chlorate (PC) sample at room temperature. The PC sample will be in different locations parallel to the surface plane of two tuned coils at a Â½â standoff distance perpendicular to the surface area. PC location predictions are made with a quadrant surface coil array using the experimental results from the dual surface coil array.

15. SUBJECT TERMS
NQR, potassium chlorate, surface coil, surface probe, decoupling, overlap, tuning, mutual coupling, NQR detection, coil array

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Abstract.
This paper focuses on detecting solid state materials that have a nuclear quadrupole moment using surface coil arrays. With surface coils in the array decoupled from one another, the location and dimension of the material can determined based on the nuclear quadrupole resonance (NQR) signal strength from the surface coil in the array. Experimental investigations will be used with two 7" diameter, single turn, surface coils overlapping for decoupling, and tuned to detect the unique 28.1MHz NQR frequency from potassium chlorate (PC) sample at room temperature. The PC sample will be in different locations parallel to the surface plane of two tuned coils at a ½" standoff distance perpendicular to the surface area. PC location predictions are made with a quadrant surface coil array using the experimental results from the dual surface coil array.

Key Terms: NQR, potassium chlorate, surface coil, surface probe, decoupling, overlap, tuning, mutual coupling, NQR detection, coil array

Introduction.

NQR is similar to NMR, but with some important distinctions. In NQR, the splitting of the nuclear spin states is determined by the electrostatic interaction of the nuclear charge density, with the external electric potential of the surrounding electron cloud, see Fig. 1. A moment expansion of this electrostatic interaction shows that the important coupling is between the nuclear quadrupole moment, indicated schematically in Fig. 1 (left), and the second derivative of the electric potential (equivalently, the gradient of the electric field) [1].

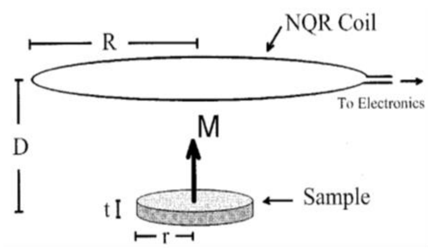

Fig.1, (left) a quadrupolar nucleus is slightly aligned by the electrostatic interaction with the valence electrons. Applying a pulse of the correct frequency flips the nuclear spin and induces an NQR signal in a pickup coil. (Right) Diagram of single surface coil for NQR detection, REF [1]

Current NQR detection techniques use individual surface coils to detect a sample at a particular standoff distance similar to Fig.1 (right). There has been NQR systems developed that can detect a single material or multiple materials using a single surface coil. The problem is those detection systems cannot determine the location or shape of the material without conducting long scanning patterns. A resolution to the problem would be a coil array with many coils in columns and rows. Most coil arrays are linear in one row. There has been no research done on a non-linear shaped surface coil array for identifying a material and determine the location or shape. While any solid state material that can produce a quadrupole moments can be investigated, this research paper investigates potassium chlorate (PC) material. The PC material detection and location investigation will start with using dual surface coils tuned and decoupled. These surface coils are tuned to the resonance frequency of PC at room temperature, which is 28.1MHz. The resonant frequency has a temperature coefficient of 3.5 kHz per degree Celsius. The following sections of this paper will describe the, surface coil design, decoupling of the coils, NQR signals of PC at different locations, and predicted results of PC locating using a four surface coil array in a quadrant arrangement.

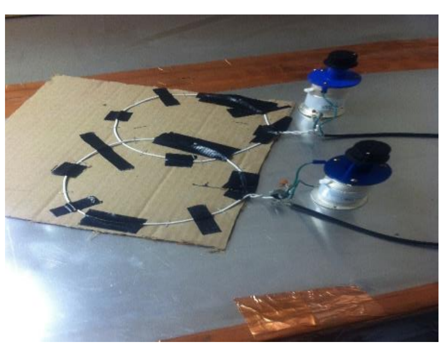

Fig.2, Decoupled dual surface coils tuned and matched outside of RF shield

Dual Surface Coils.

As shown in Fig.2, the surface coils are taped in a 7 inch diameter single turn coil onto a cardboard. The coil resistance is 0.3 ohms on each coil. Both coils were connected to a HP 8753D network analyzer through coaxial cables with 50 ohm BNC connectors while being tuned to 28.1MHz and matched to 50 ohms. Each coil has a variable capacitor in series and was adjusted until coil was at 28.1MHz resonant. Exactly 376pF of fixed capacitors were added to the coil in parallel until the coil matched closely to 50 ohms. The network analyzer was not equipped to download data so screenshots were used in this research. The return loss for left coil and right coil were S_{11} =-29.89dB.

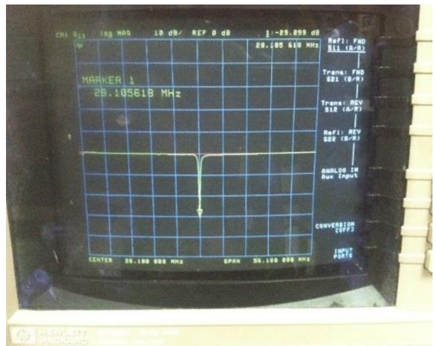

Fig.3, return loss of probe left and probe right, respectively

Decoupling.

The most important aspect in building a coil array is to minimize the mutual coupling that exists between neighbouring surface coils. Mutual coupling causes splitting for the resonance frequency and disrupt phased array transmit and receive pattern. Several technique such overlapping of coils, insertion of capacitors between coils, and network decoupling interface are some of the methods used to reduce mutual coupling between coil elements [4]. In this paper, the focus is on overlapping coils for decoupling. When the surface coils shown in Fig.1 overlapped, there is a certain position of overlap at which the magnetic flux from the left coil passing through the right coil is zero. An S_{21} measurements were taken using the network analyzer to determine the mutual coupling. Maximum decouple is shown when coils are a 1 ½ inch overlapping. The S_{21} was -15.6dB at 28.1MHz. With the surface coils tuned to the PC sample and coils decoupled, the detection of PC located in the left or right coil without any neighboring ringing can be achieved.

Detecting and Locating PC.

This is NQR setup has a one channel transmitter and one channel receiver. The left or right coil is connected to the transmitting/receiving channel one at a time. When one coil is in use, the other coil has a 50ohm load connected. With a 28.1MHz RF pulse at 150Vrms for 400us transmitting into the left or right coil, the PC sample is induced with a RF magnetic field to produce a flip angle in the chlorate nuclei of PC. With a known gyromagnetic ratio of 26.1 x 10^6 rad/sT, the flip angle is at 60 degrees. The spectrometer was set to have a delay to by-pass the ring-down of the coil Q and noise from the LNA switching on. There was a wait time of 0.25s after each NQR signal was captured, which is half the actual T1 needed at room temperature.

This NQR FID pulse sequence will be applied in different sample-coil configurations. In each configuration, 500 signal averages were taken before the data is stored for post processing. The PC sample is Fig.5 was placed a half inch above the coils perpendicular to the surface and remains at this standoff distance throughout the different experimental configurations.

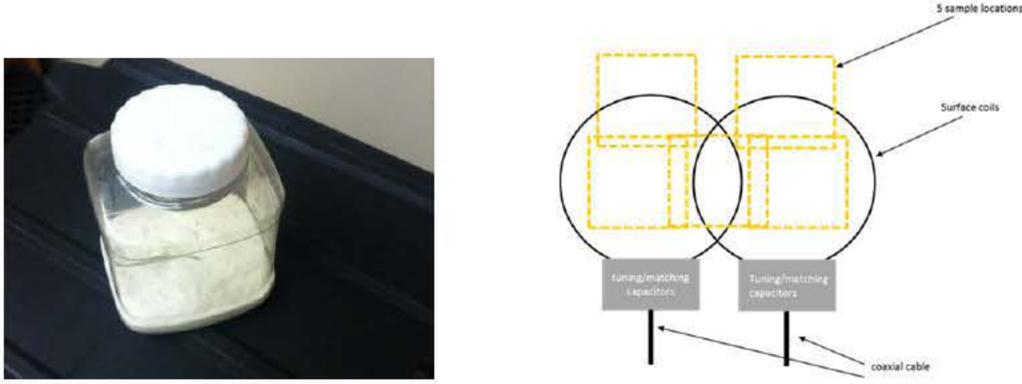

Fig.5, potassium chlorate in container outside of the RF shield (left), and diagram of both left and right coil configurations (right)

The first configuration is with the NQR setup connected to the right coil. The data is collected with PC sample in center of the right coil, in the middle of the right and left coil and with the sample in the center of the left coil. The second configuration, the NQR setup is connected to the left coil and the same movements repeated. Also, there were data collections of the sample centered at the tangent point of the coil of the left and right coil.
After the data is collected, the real and imaginary data is post processed at plotted using MATLAB. The graphs show the magnitude of the real and imaginary signals in time and frequency domains. Throughout the experiment, the spectrometer was adjusted to observe at a center frequency 7 kHz offset from 28.1MHz to verify that the NQR signal is from the PC sample. The y-axis magnitude in Fig.7 is generated from the spectrometers 16 bit levels receiver at +/-0.5V.

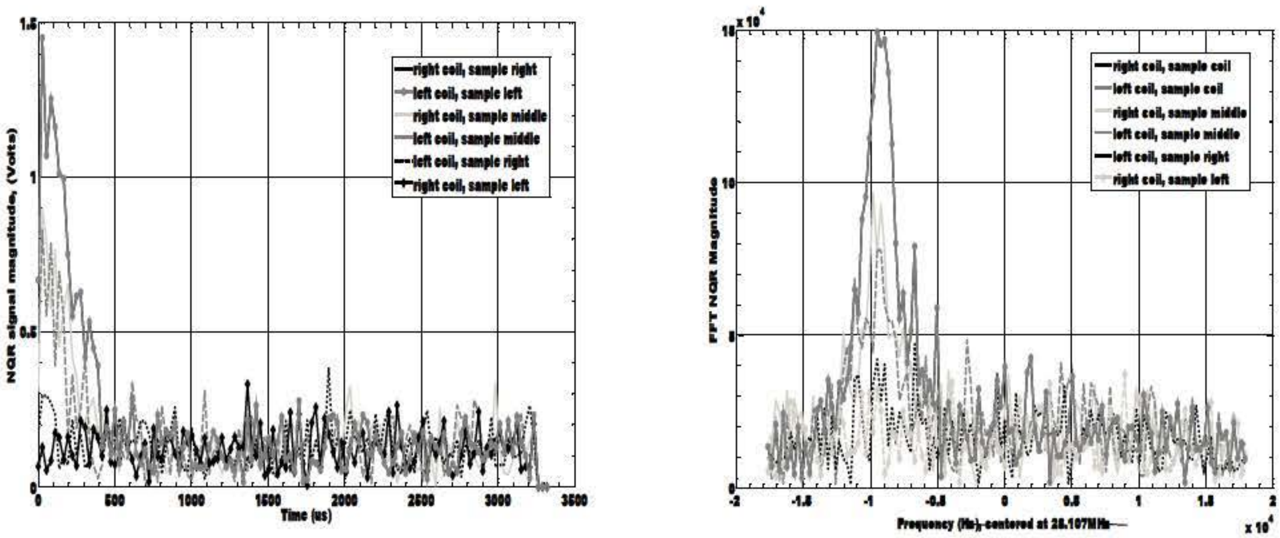

Fig.7, (left) time domain of the magnitude of the NQR signal from the different configurations, and (right) the FFT of NQR signal from different configurations with the center frequency being 28.1MHz

Given the above results in the previous section, the NQR signal strength is highest when the sample is in the middle of the left or right coil at the set standoff distance. When the sample is in the middle of both coils, the signal is still strong in both coils, but not as strong as the sample in the left or right coils. This could give a false location if a threshold were set because the signal would show that the PC sample is large enough to be under the surface area of both coils, but in reality, the PC sample is in the middle. The NQR signal from the left or right coil, with the sample under the opposite coil, gives a weak signal equivalent to a sample not being present.

Quadrant Surface Coil Predictions.
Suppose a four surface coil array was designed with the each coil tuned and match to the 28.1MHz and 50ohms, respectively, like the dual surface coil array. The four coil array would be in a quadrant arrangement with two

dual overlapping coils overlapping another dual surface coil array in parallel. If the weak NQR signal from "coil left sample right" or vice versa could be the threshold for PC sample detection, the predicted results of locating the sample in a quadrant four surface coil array would show false locations as show in Fig.8. If a threshold were set at the signal strength of the "coil left or right sample middle", the PC sample locating could be more accurate.

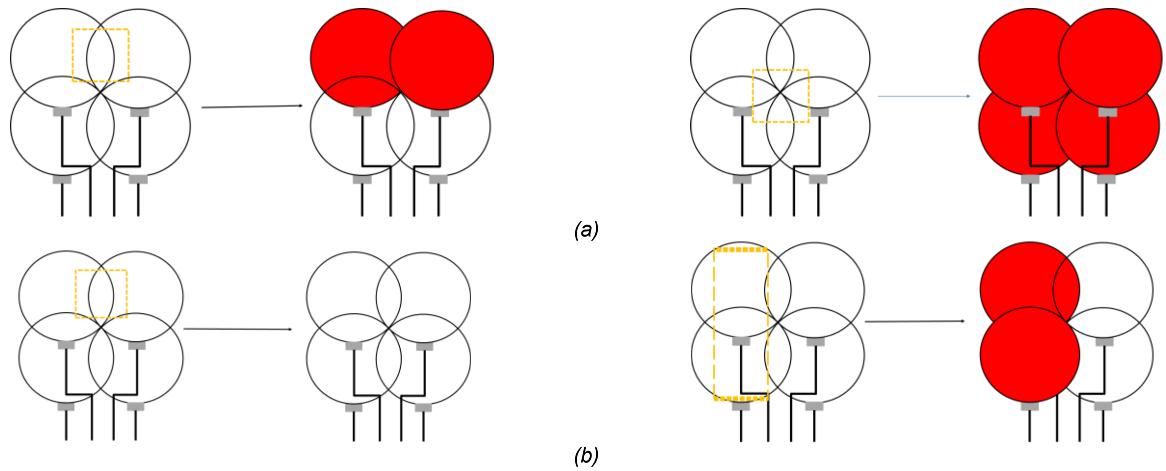

Fig.8, (a) threshold set at "coil left sample right" or vice versa, (b) threshold set at detection with sample in the middle. The red coil marks a PC sample detection location. A longer sample size is needed to get more than one detection red in the (b)

Conclusion.

Dual and quadrant surface coil arrays can locate materials within the surface area of the coil array. This materials have to have quadrupole moments between the nucleus and electron clouds of the material's atoms. Since the quadrant coil array is a duplication of two pairs of dual surface coils, it was easier to conduct experimental investigations on the dual surface coil and predict the results of the quadrant surface coil. Since the experimental investigation was used with one receiver channel, the coil arrays were switching coil arrays. In this investigation, it was stated that the coil not in use would be connected to a 50 ohm load. The results with the unused coil having an open circuit produced no change in results. This paper showed that the threshold setting helps determines the accuracy of sample location within the surface area of the coil array.

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